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Spin from oblique impact of batted sports balls

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Abstract

The spin of a batted ball is needed to describe the ensuing trajectory. The following considers experimental spin measurements collected by impacting a stationary ball with a swinging bat. Each collision was recorded with two high speed cameras from which velocity and positional data was obtained. Both baseballs and softballs were hit at swing speeds from 28m/s to 39m/s producing ball trajectories from 0° to 25°. The effect of hit angle, barrel surface friction, bat circumferential moment of inertia, barrel diameter and ball inertia were observed using four different bat constructions and two different ball types. Ball spin increased with hit angle and bat speed, and decreased with ball inertia. Ball spin was not influenced by barrel surface friction, barrel diameter, or bat circumferential moment of inertia.

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Keywords: Oblique impact baseball; spin, batted baseball

1. Introduction

An important characteristic of the ball and bat collision is the resulting spin imparted on the ball. To accurately predict the ball path it is necessary to understand how the ball rotates from impact with a bat. Spin of the ball directly affects the lift and to a lesser degree drag, and the final flight distance of the ball. A number of factors are believed to influence the ball spin, including bat and ball surface friction, bat circumferential inertial, ball inertia, and oblique collision angles. While ball spin increases lift, the oblique collision needed to impart spin reduces the linear momentum transferred to the ball. Thus, the competing benefits of ball speed and spin must be balanced to achieve maximum distance [1].

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Launch angle, spin, and ball velocity are used to predict ball flight [2]. Measuring the angle and spin of a batted ball in a game setting poses many challenges. The collision duration of a batted ball lasts about one millisecond [3] with the bat and ball moving at relative speeds near 58 m/s. For this reason, spin measurements are typically conducted in a laboratory setting.

Traditionally, the bat-ball interaction from oblique collisions has been described as either sliding to rolling, depending on the angle of impact. Recently, Nathan projected baseballs against ridgid cylinders and measured the velocity and spin vectors before and after impact [4]. He found that the ball did not roll off the cylinder, but griped the surface and stretched. The stretching allowed the friction force to reverse direction which led to higher spin than can be obtained by rolling alone. As the incident angle increased, the ball ceased to grip the bat and began to slip. Cross studied the grip-slip behaviour of sport balls on a flat surface, including the baseball, and also found that balls either grip or slip on surfaces, but do not roll [5,6]. These novel observations have provided insight into the mechanics of ball spin, but have not involved high speed bat-ball impacts where ball deformation is large. In the following the rotational speed and hit angle of baseballs and softballs, impacted by four different bats and at speeds representative of play, were recorded. The effect of surface roughness and bat and ball inertia were also considered.

2. Methods and experimental setup

The aim of this work was to measure the linear and rotational speeds of the bat and the ball at collisions representative of play. A machine was used to swing bats against a stationary ball resting on a tee. Bats were swung to achieve speeds between 28m/s and 39m/s at the impact location. Bats were fastened onto a rotating pivot with a flexible clamp. A 10mm thick piece of 32A durometer rubber was placed between the clamp and the bat handle. This rubber grip kept the bat from slipping out of the machine and allowed compliancy to simulate a batter's hands. Each impact was measured with two cameras (1200x800 pixels). The cameras were placed in the plane of the swinging bat. Camera 1 was set to a 0.58m by 0.89m viewing plane and recorded the bat-ball impact at 3000 frames per second. It was aligned collinear with the bat at impact as shown in Figure 1. Camera 2 was set to a 1.0m by 1.5m viewing plane and recorded the impact at 1000 frames per second, also shown in Figure 1.

Each hit was tracked with 2-D tracking software (ProAnalyst). The bat tip speed, V, and swing plane angle, θ_B, were determined from Camera 1 using a tracking dot on the end cap of the bat. The hit ball speed, v_h, and angle, α_h , was also obtained from Camera 1. Because of the large ball deformation at

Fig. 1. Representative views from Camera 1 (left) and Camera 2 (right) used to measure bat and ball speed and rotation.

Table 1. Surface roughness and inertia of bats and balls.

Type	ID	Finish	Surface roughness (10^{-4} mm)	I_c or I_b (kg-mm²)
Baseball bat, wood	B-W	varnish	10.3	154
Baseball bat, metal	B-S	smooth gloss	4.4	311
Baseball bat, metal	B-R	rough powder coat	540	305
Softball bat, composite	S-S	smooth gloss	1.5	202
Softball	S	12 inch circ., leather	34.1	185
Baseball	B	8.8 inch circ., leather	34.0	76

impact and the relatively short bat-ball contact duration, the incident ball-bat angle was not found. The relative ball-bat angle, α_r, was obtained from $\alpha_r = \alpha_h - \theta_B$, as indicated in Figure 2. Camera 2 was used to measure ball spin, ω_b. Each ball was marked with a series of four tracking dots forming the outside corners of a 38mm square pattern. The ball was placed on the tee so that the four dots would rotate and encompass the centre of rotation of the ball after being hit. Two of the four dots were tracked for each hit. Impacts where at least one dot did not rotate about the centre of rotation were not included in the dataset. Each dot's coordinates were used to calculate the angle of rotation from each video frame which were then used to find ω_b. The spin was averaged over the time the ball left the bat to the time when the ball left the viewing plane (typically 15 frames).

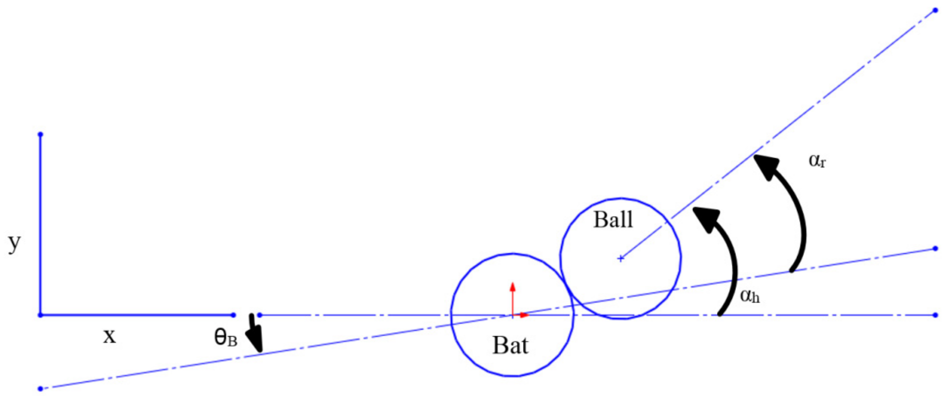

Fig. 2. Ball and bat angles at impact. Arrows indicate positive direction for measurements.

Bat roughness was classified by measuring average depth of the surface imperfections (SURTEST-SJ201). Roughness was reported as the average depth measured across a 3.8mm section of the barrel. The bats with a glossy finish had the lowest surface roughness and the bats with powder coat had the highest roughness (see Table 1). The roughness of the ball leather cover is also reported in Table 1.

Players are typically concerned with the inertia resisting their swing motion. For the case of oblique impacts and imparting ball spin, the bat circumferential inertia, I_c, is of interest. Given a solid and hollow bat of the same weight, for instance, the hollow bat will have higher circumferential inertia and potentially impart more spin to the ball. By suspending the bat in a bifilar pendulum [7] and measuring the time for one period, T, I_c was found as:

$$I_c = MgTb^2/4\pi L \tag{1}$$

where M is the mass of the bat, g is gravity, b is the length from the centre of rotation to the outside of the torque arm, and L is the length of the pendulum.

Ball rotational inertia, I_b, was calculated from a uniform sphere by

$$I_b = (2/5)mr^2 \qquad (2)$$

where m is the mass of the ball and r is the radius of the ball.

3. Results and discussion

The relationship between ball spin, ω_b, and α_r is shown in Figure 3. Due to the constraints of the experiment, 62% of the swings fell within 28.2m/s ± .45m/s and 36.7m/s ±.45m/s. Considering the two linear fits from each group of hits, ω_b increased at nearly the same rate as V (ω_b increased 15% when V increased 18%). Ball spin can, therefore, be normalized to a nominal bat speed, V_n, since V and ω_b increased at approximately the same rate. The normalized ball spin, ω_n, was obtained by [4]

$$\omega_n = \omega_b(V_n/V) \qquad (3)$$

where V_n =34.6m/s and was the average of all swings. Ball spin is shown as a function of α_r for all hits in Figure 4. As expected, ω_n was affected most by α_r and I_b. An inverse relationship was found between ω_n and α_r, where ω_n increased 41% when I_b decreased 44%.

Similar spin rates of softballs and baseballs were found by Martin [8], which were measured using Doppler radar in a live game setting. Martin found that baseballs spin 1.67 times faster than softballs, which is comparable to the 1.78 factor observed in this work. Note that Martin reported the hit angle, not the relative bat-ball angle considered in this work.

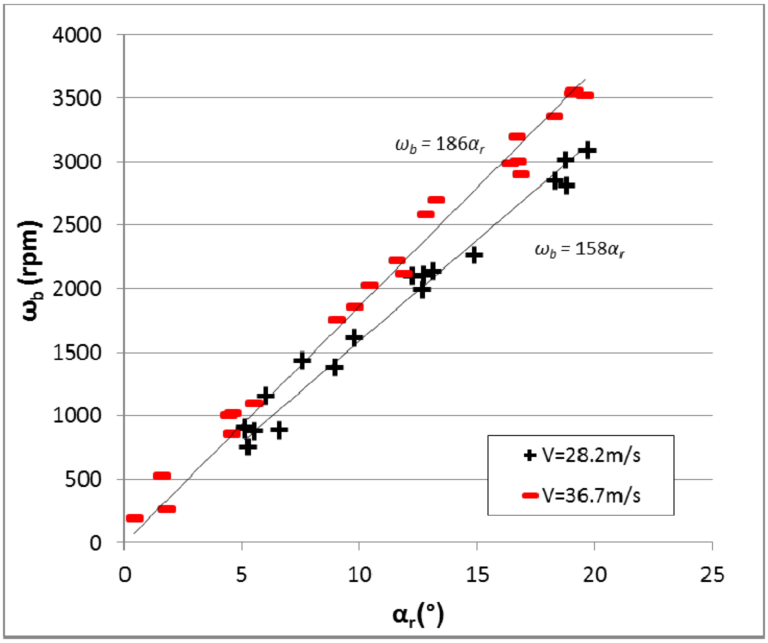

Fig. 3. Observed spin of baseballs against all bat types as a function of the relative ball-bat angle, αr.

At the highest α_r (~25°), slip was not observed. At α_r =25° the spin imparted on the ball was over 3500 rpm. Due to the constraints of the experiment, α_r > 25° could not be produced. Thus, surface friction (i.e. slip/no slip condition) was not be studied.

The impacts in Figure 4 involve bats with high (hollow barrel) and low (solid barrel) I_c. Also included in Figure 4 are bats of different diameter (S=57mm and B=63.5 mm). While it is likely that bat diameter had an effect on the hit angle for a given bat-ball offset, in all cases ω_n was independent of I_c. The bat circumferential inertia, I_c, is listed for each bat in Table 1, where it has similar magnitude and range as I_b. This suggests that the grip phenomenon observed by Nathan and Cross at slow speeds and on rigid surfaces is also active with bat impacts at high speeds and plays a greater role on ω_b than I_c.

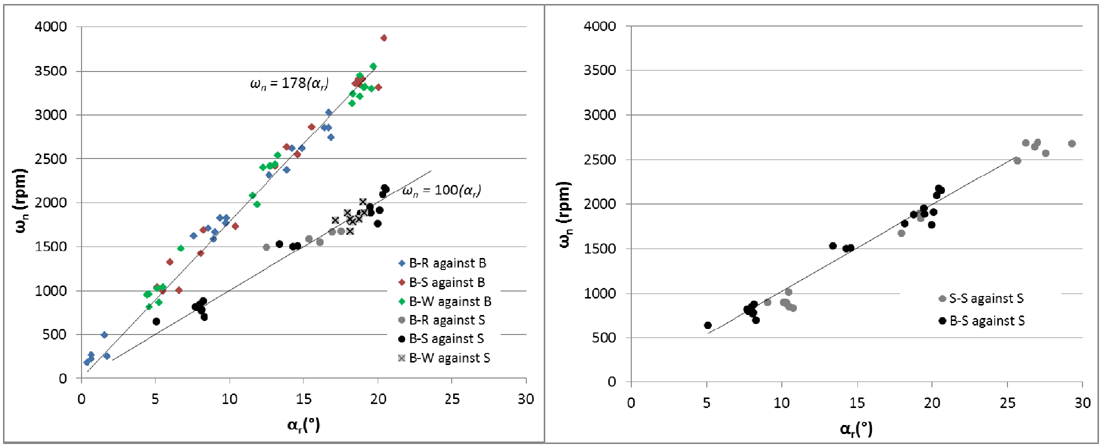

Fig. 4. Results for normalized spin rate as a function of the relative ball-bat angle for softballs and baseballs against baseball bats (left) and for softballs against softball and baseball bats (right).

4. Conclusion

The spin of batted baseballs and softballs were measured to better predict batted ball flight paths. A slip condition was not observed, even at hit ball angles as high as 25°. Ball spin was not affected by the surface friction of the bat, the diameter of the bat, or the circumferential inertia of the bat. Ball spin was affected by the hit angle, speed of the bat-ball impact, and rotational inertia of the ball. Ball spin was observed to increase at approximately the same rate as bat speed and hit angle increased, and ball inertia decreased.

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References

[1] G.S. Sawicki, M.Hubbard and W.J. Stronge. "How to hit home runs: Optimum baseball swing parameters for maximum range trajectories," *American Journal of Physics*, Vol. 71, No. 11, 1152-1162 (2003).

[2] R.G. Watts and S. Baroni, "Baseball-bat collisions and the resulting trajectories of spinning balls," *Americal Journal of Physics*, Vol. 57, No. 1, 40-45 (1989).

[3] L.V. Smith, "Evaluating baseball bat performance," *Sports Engineering*, Vol.4 205-214 (2001).

[4] A.M. Nathan, "Spin of a batted baseball" *Proceedia Engineering*, Vol. 34, 182-187 (2012).

[5] R. Cross, "Grip-slip behavior of a bouncing ball," *American Journal of Physics*, Vol. 70, No. 11, 1093-1102 (2002)

[6] R. Cross and A.M. Nathan, "Scattering of a baseball by a bat," *American Journal of Physics*, Vol. 74, No. 10, 896-904 (2006).

[7] J.W. Then and K. Chiang, "Experimental determination for moments of inertia by the bifilar Pendulum method," *American Journal of Physics,* Vol. 38, No. 4, 537-539 (1970).